

"Real-Time Vertical Temperature, and Velocity Profiles from a Wave Glider"

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LONG-TERM GOALS

In the past decade, the Lagrangian Drifter Group at Scripps Institution of Oceanography (SIO) has taken part in several ONR-sponsored oceanographic experiments with in-house developed autonomous instruments designed to measure vertical profiles of water temperature and three dimensional water velocity as well as atmospheric parameters. This class of instrument is termed ADOS (Autonomous Drifting Ocean Station) and several variants exist. The ADOS-A, which measures temperature and velocity (A for ADCP) profiles in the 0-200 meter range, was used in the South China Sea during the NLIWI experiment [Centurioni, 2010]. The Restrained (R) version of the latter, the R-ADOS-A was used during the QPE experiment [Gawarkiewicz *et al.*, 2011] to control the displacement of the sensors due to the swift tidal currents that occur near the shelf break of the East China Sea continental shelf. The M-ADOS-A, which is an ADOS-A fitted with a suite of meteorological (hence the M) sensors (sea-level air pressure, wind, and solar radiation) was air deployed successfully in the western Pacific Ocean in September 2010 during the ITOP experiment. ADOS platforms are also deployed by the NOAA funded Global Drifter Program in the north Atlantic during the hurricane season to measure the thermal structure of the ocean ahead of storms and in their wakes. Both the ADOS-A and the M-ADOS-A are freely drifting non-Lagrangian (i.e. non water-following) devices and the R-ADOS-A has a passive position-control feature that consists of a variable-length section of metal chain designed to exert a significant drag at the bottom without blowing down the surface expression of the instrument in strong currents. The endurance of the ADOS class of instruments is typically one to three months.

For some ocean applications, however, it is highly desirable to have an active control of the navigation and position of the instrumented platform and an endurance longer than that of the ADOS system (~two months on a single deployment).

The long-term goal of this research is to explore the technological advances in unmanned vehicle technology to achieve profiling capabilities from the surface to a depth of 100 m from autonomous vehicles capable of navigating through pre-set way-points for a time period in excess of six months.

Autonomous platforms with long endurance are particularly useful to cut down ever-increasing ship-time expenses and to access areas closed to civilian ships due to safety reasons. Possible scientific applications of the proposed technical development include: long-term detection of large amplitude

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non-linear internal waves in critical and sensitive areas from coherent, quasi-stationary arrays, ocean measurements of temperature, salinity and currents to be used as boundary conditions and/or for data assimilation purposes into numerical models and detection of propagating thermocline disturbances, such as the ones which are thought to precede El Nino events in the eastern North Pacific ocean [*Lee and Niiler, 2010*].

OBJECTIVES

The specific objective of this effort is to demonstrate that a Wave Glider carrying an underwater winch able to spool a 100 meter long tether fitted with a Seabird SBE-39 TP sensor and one Acoustic Doppler Current Profiler is able to keep position within a 5 km X 5 km box and, additionally, to navigate on a six-months long missions while performing vertical temperature profiles. We anticipate that the proposed methodology will have a minor impact on the navigation capability of the Wave Glider.

APPROACH

In 2009, Liquid Robotics navigated a Wave Glider from San Diego to Hawaii on a 82 day-long voyage that covered approximately 2500 nautical miles (<http://liquidr.com/missions/ocean-crossing/>). New longer missions are planned and underway (<http://liquidr.com/pacx/pacxspecs>). This has demonstrated the exceptional endurance of the Wave Glider. We wish to exploit this characteristic and add high temporal and spatial resolution, upper ocean temperature and 3-D current profiling capabilities to the device. The proposed approach is to develop, in collaboration with industry, a small, rugged and submersible winch capable of profiling to a depth of at least 100 m.

Tests have already been run with a Wave Glider fitted with a 38 m long, $\frac{1}{2}$ " diameter tether with a streamlined hydrophone assembly attached at the lower end of the tether. A multi-conductor $\frac{1}{2}$ " thick cable was required in order to power the hydrophone and to send the data to the electronics housed in the surface expression of the Wave Glider. So configured, the wave-glider was able to navigate offshore from the Scripps pier under average swell conditions (Dr. Sean Wiggins at the Scripps Whale Acoustic Laboratory, pers. comm.). The winch system is being designed to be small enough to not interfere significantly with the navigation and station keeping capabilities of the Wave Glider. Based on Dr. Wiggins' experience of a towed tether, we are confident that this goal can be achieved.

WORK COMPLETED

Several existing winch systems were considered for use or adaptation to the Liquid Robotics Wave Glider. Size, weight, and power consumption were the largest constraints, resulting in the narrowing to two candidate winches. The first candidate winch is produced by Nichiyu Giken Kogyo Company (NGK) in Japan, and the second is a concept winch developed with MacArtney Inc.

The NGK winch is a component of NGK's SEA-SAW profiler product, a self-profiling mooring system designed for long-term deployment at depths of 100m. The winch component of the SEA-SAW system was removed and modified to mount onto a standard Wave Glider sub (Figures 1 through 3).



Figure 1: Top view of the Wave Glider fitted with the NGK winch.

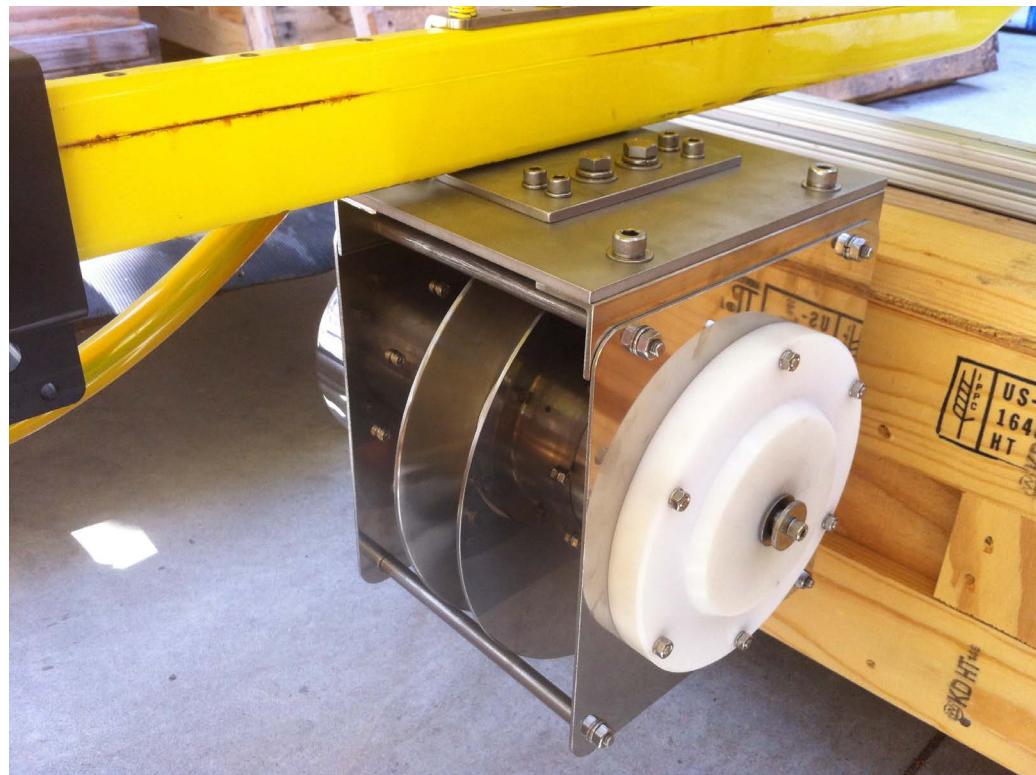


Figure 2: Detail of the NGK winch fitted to the propulsion paddle of the Wave Glider.

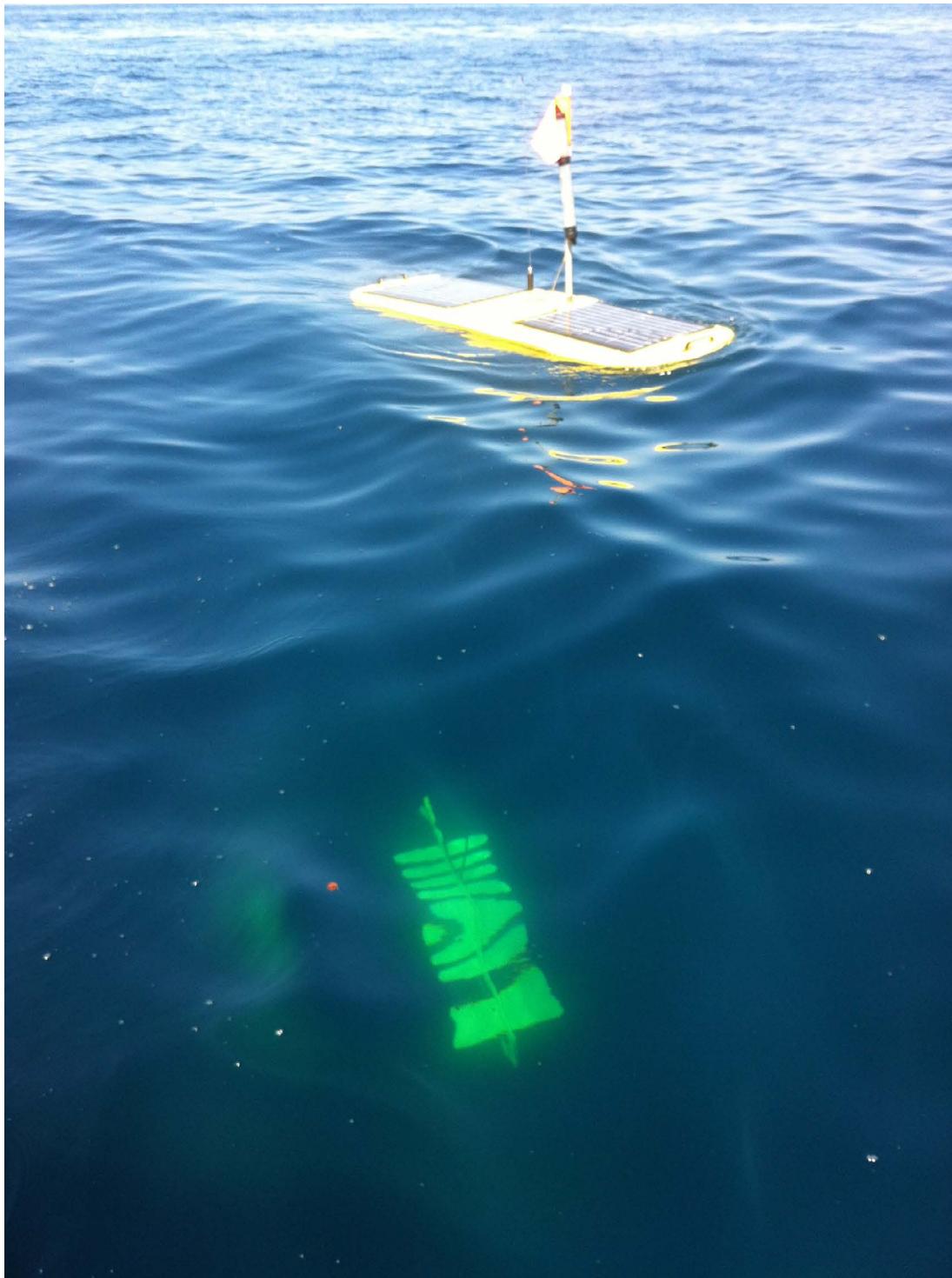


Figure 3: Wave Glider fitted with the NGK winch deployed.

This assembly was field tested off the coast of SIO in 0.5 to 1 meter swell and negligible wind. Deployment of the Wave Glider + Winch occurred from a 25 ft. ribbed boat at 17:45 UTC on 8/17/12, and was recovered at 18:27. During the deployment, GPS position was transmitted 9 times at regular intervals, along with heading, desired heading, and distance over ground. The Wave Glider had

previously been run with a towed hydrophone, and below is a plot of the positions from both trials (Figure 4).



Figure 4: Navigation tracks of the wave glider fitted with a short tow cable (yellow) and with the NGK winch (red track).

The positions in the NW are the hydrophone-towed assembly (yellow line), with a brief pause for recovering the Wave Glider and mounting the NGK winch, followed by the telemetry of the towed-winches body (red line). Beyond the initial acceleration period after deployment, lasting less than 4 minutes, the Wave Glider continued course with an average speed of 0.88 knots, which compares relatively equivalent to the hydrophone-towed average speed of 1.06 knots. The comparison between the actual heading and desired heading at each position can be used as a metric for ability to navigate, or agility of the wave glider with a towed body. The winch-towed body averaged 8.78° within desired heading, compared to the hydrophone-towed body's 19.14° . To the right is an image of the deployed Wave Glider + Winch. Current and wave spectra were not recorded during both trials, but conditions appeared to be similar between each test. Speed through water measurements will be taken in future testing, and can help to predict station keeping capability in various wave, wind, and current conditions.

The second candidate winch is a concept winch, currently in production by MacArtney Inc. and due for delivery of the first two systems by November 1, 2012. The winch specifications were designed in cooperation between SIO and MacArtney specifically for use on Wave Glider platforms. This winch will feature a low-drag profile, multi-diameter wire guide, small size and weight advantages compared to the NGK winch, and a 100m wire capacity. Below is a drawing of the concept winch, reflecting projected size and drag profile (Figure 5).

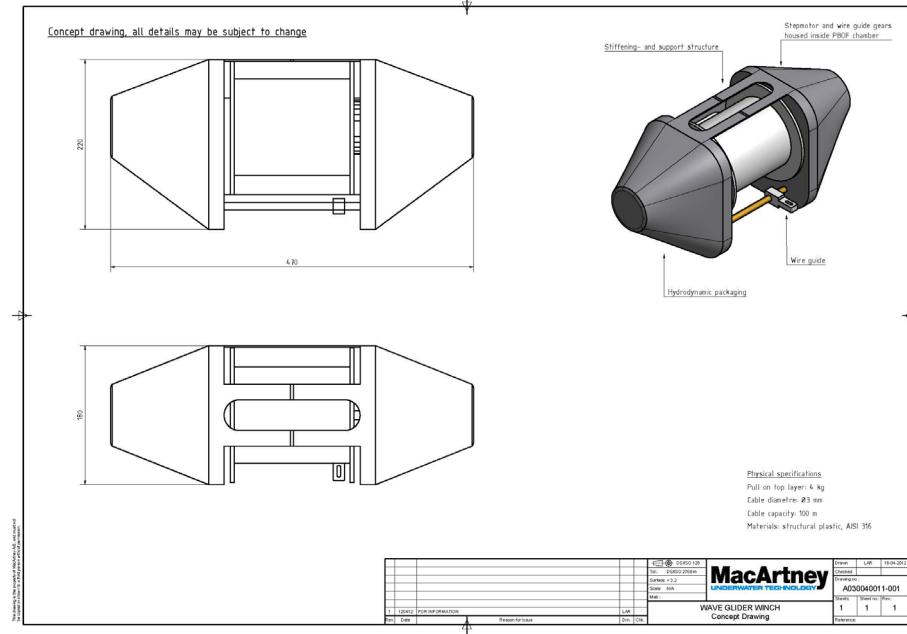


Figure 5: Conceptual schematic of the underwater winch designed by SIO/MacArtney.

For either winch system, power consumption is a considerable limiting factor for mission endurance and profiling intervals. A surface auxiliary battery is being developed between SIO and Liquid Robotics for integration into their aft payload and solar panels. An 1100 Ah rechargeable battery pack will be run down to the winch from the surface expression.

RESULTS

Beyond the initial acceleration period after deployment, lasting less than 4 minutes, the Wave Glider continued course with an average speed of 0.88 knots, which compares relatively equivalent to the hydrophone-towed average speed of 1.07 knots. At each telemetry datum, the Wave Glider records the actual heading as well as the desired heading. The comparison between the two can be used as a metric for ability to navigate, or agility of the wave glider with a towed body. The winch-towed body averaged 8.78° within desired heading, compared to the hydrophone-towed body's 19.14° .

The main conclusion is therefore that the underwater winch approach (with the NGK winch) improves the navigation asset of the wave glider. Note that the winch did not have a slender shell cover. We anticipate that the newly made winch fitted with a shell streamlined in the direction of the forward motion of the glider will have considerably less forward drag, thus resulting in even better navigational and station keeping performance. Further testing including effects of biofouling must be investigated moving forward

IMPACT/APPLICATIONS

As mentioned in the introduction, this technology should find applications in regions where a coherent array needs to be maintained in a small region of a few hundred km^2 (mesoscale) and to access unsafe regions such as the Arabian Sea.

RELATED PROJECTS

None

REFERENCES

Centurioni, L. R. (2010), Observations of Large-Amplitude Nonlinear Internal Waves from a Drifting Array: Instruments and Methods, *J Atmos Ocean Tech*, 27(10), 1711-1731.

Gawarkiewicz, G., et al. (2011), Circulation and Intrusions Northeast of Taiwan: Chasing and Predicting Uncertainty in the Cold Dome., *Oceanography*, 24(4), 110-121.

Lee, D.-K., and P. Niiler (2010), Influence of warm SST anomalies formed in the eastern Pacific subduction zone on recent El Nino events, *J Mar Res*, 68(3-4), 459-477.